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Procedia Computer Science 77 (2015) 151 – 157

Procedia
Computer Science

ICTE in Regional Development

Modelling of Regional Transit Multimodal Transport Accessibility with Petri Net Simulation

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Abstract

Accessibility is the main characteristic of a transport system. It determines the locational advantage of an area (a region, a city or a corridor) relative to all areas. The important role of transport infrastructure (i.e. networks and transport services) for spatial development in its most simplified form implies that areas with better access to the locations of input materials and markets will be more productive, more competitive and hence more successful than more remote and isolated areas.

The paper presents an approach for modelling of regional transit multimodal transport accessibility with Evaluation Petri Net (E-Net) simulation as part of regional Intelligent Transport System with many specific aspects of accessibility analysis and modelling: (1) multilevel structural hierarchy; (2) multifunctional objects of modelling; (3) different nature of transport flow (passenger and freight); (4) heterogeneous components of the modelling system; (5) multimodal transport infrastructure and others.

The dynamic behaviour of the model at various levels of abstraction is discussed based on analytical properties of Petri Nets.

Peer-review under responsibility of the Sociotechnical Systems Engineering Institute of Vidzeme University of Applied Sciences

Keywords: Accessibility; Intelligent transport systems; Modelling; Petri Net

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1. Introduction

The important role of transport infrastructure for regional development is one of the fundamental principles of regional economics. Accessibility is the main characteristic of a transport system. It determines the locational

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Peer-review under responsibility of the Sociotechnical Systems Engineering Institute of Vidzeme University of Applied Sciences
doi:10.1016/j.procs.2015.12.373

advantage of an area (a region, a city or a corridor) relative to all areas. This process is commonly performed with the assistance of travel demand models that provide information on current and future transportation system operations. Such models are part of a regional intelligent transport system (ITS) oriented on use of information and communication technologies (ICT) applications which aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and smarter use of transport networks. The advanced traveller information system (ATIS) is one of the most widely used types of ITS for this purpose. ATIS implements a wide range of ICT to assist travellers in making informed decisions regarding trip departures, optimum routes, and available modes of travel. In practice, the ATIS provides functions of decision support system (DSS).

The term Decision Support System is widely used for any kind of system, which provides valuable information necessary to support decision-making processes. These systems are appreciated in highly complex environments where problems or tasks have varying degrees of structuration; some of them are unstructured or semi-structured. The transport system is complex and safety-critical and is one of the main application of various DSS. There are a lot of DSS models for transport applications, for example, for rail[1,2,3], ocean[4], urban[5,6,7] transportation systems and for multimodal transport networks[8,9,10,11,12,13].

The above-mentioned computer-based systems to support decision making abound in elaborate functionality but are often difficult to use effectively in a real business environment, and are therefore often not used at all. Designers of DSS applications are appealing to the reliability of the model to determine their expectations about future interactions with the world. Such expectations point to mental, or cognitive, modelling that is a characteristic of human consciousness this internal, personal model making seems far removed from programming.

Theoretical studies on rational decision making, notably that in the context of probability theory and decision theory, have been accompanied by empirical research on whether human behaviour complies with the theory. It has been rather convincingly demonstrated in numerous empirical studies that human judgment and decision making is based on intuitive strategies as opposed to theoretical rules. These intuitive strategies, referred to as judgmental heuristics in the context of decision making, help decision makers reduce the cognitive load. Formal discussion of the most important research results along with experimental data can be found in[14, 15].

Metropolitan planning organizations develop regional transportation plans and programs to accommodate mobility needs within their regions. Most of accessibility studies concentrated on the accessibility of cities, i.e. network nodes which are assumed to represent the whole metropolitan area or even a larger region. This presents two problems:

- Accessibility modelled for network nodes ignores that accessibility is continuous in space. The decline of accessibility from the central node (centroid) of a region to smaller towns and less urbanised parts of the region is not considered.
- The quality of the interconnections between the high-speed interregional and the low-speed local transport networks cannot be taken into account. Yet the ease of getting from home or office to the nearest station of the high-speed rail network or the nearest airport may be more important for the accessibility of a location than the speed of the long-distance connection from there.

The task of the regional accessibility models is to provide the base for an analysis of the restrictions and opportunities for daily life provided by the transport infrastructure in the regions to the population and economic actors. From the planning point of view it is essential to have mode choice, due to the massive amount of incurred in transportation systems.

In the paper the DSS for choice alternative of routes in the large-scale transportation transit system embedding the heuristic approach and also integrating simulation was developed. A detailed description of the developed simulation model is beyond the scope of this paper.

2. General approach for heuristic based decision support in transport transit system

The large scale transportation transit system is presented by directed finite graph which is an ordered pair $= (V, A)$, where $V = \{v_i\}, i = \overline{1,n}$ is set of finite vertices (airports, railway, bus and bike stations and other passenger terminals) and $A = \{a_j\}, j = \overline{1,m}$ is set of finite arcs (transport lines between different terminals).

Under these conditions, decision-making can be used by systems with customized decision models. The main idea behind this approach is automatic generation of a graphical decision model on a per-case basis in an interactive effort between the DSS and the decision maker. The DSS has domain expertise in a certain area and plays the role of a decision analyst. During this interaction, the program creates a customized influence diagram, which is later used for generating advice. The main motivation for this approach is the premise that every decision is unique and needs to be looked at individually; an influence diagram needs to be tailored to individual needs[16].

The urban and inter-urban public transport system includes a variety of patterns such as normal buses, rail and air transit, trams, taxi and so on. Each kind of traffic tools provides different services to passengers with different speeds, carrying capacity, prices and comfort levels. For a short-distance trip, one can travel by means of regular ground transportation, and for the distance between the starting place and bus stop, one can walk or ride a private/public bike to get to the bus stop; the long-distance trip can be turned into the trip combination of various public transport modes[17].

Example of alternative travel routs from regional start point X to destination point Y is shown at the Fig. 1. The matrix of alternative routes $R = |r_{ij}|$, where $i = \overline{1,n}$ – transport alternatives, $j = \overline{1,m}$ – levels of transit. There are five alternatives in the example of Fig.1:

- alternative 1 with one level of transit (private car),
- alternative 2 with five level of transit (walking-local bus-intercity bus-local bus-walking),
- alternative 3 with four level of transit (walking-local bus-train-taxi),
- alternative 4 with five level of transit (walking-local bus-train-tram-walking),
- alternative 6 with six level of transit (walking-local bus-train-walking-public bicycle-walking).

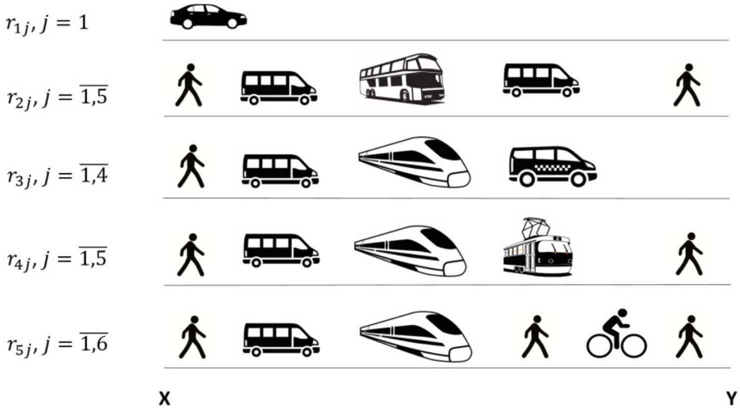


Fig.1. Public transport combined trips

The basis for making decisions on the choice of route variant from the original point X to destination point Y is a set of possible alternatives of travel and their attributes (travel time, cost and schedule). The decision making process in the large-scale transportation transit system in this case can be described by the heuristic procedure given in Fig. 2.

On the base of set of all possible routes and required travel demand (from point X to point Y) DSS generates a matrix of alternative routes $R = |r_{ij}|$, where $i = \overline{1,n}$ – transport alternatives, $j = \overline{1,m}$ – levels of transit. In the next step we need to define the Criterion of Preference (CoP). We need to choose one from two possible CoP – cost or time of travel. After that the total value of the CoP for each alternative route $i = \overline{1,n}$ is calculated:

$$CoP_i = \sum_{j=1}^{m} c_{ij} \ or \ CoP_i = \sum_{j=1}^{m} t_{ij}, \ i = \overline{1,n} \tag{1}$$

Finally, on the basis of a comparison between transport alternatives DSS, choosing the best one, for which the minimum of CoP is achieved:

$$CoP_{opt} = min(CoP_i | \, i = \overline{1,n}) \tag{2}$$

In the paper, the approach to modelling heuristic based decision support systems was performed using the simulation based on Petri Nets with customized decision procedure shown in the Fig. 2.

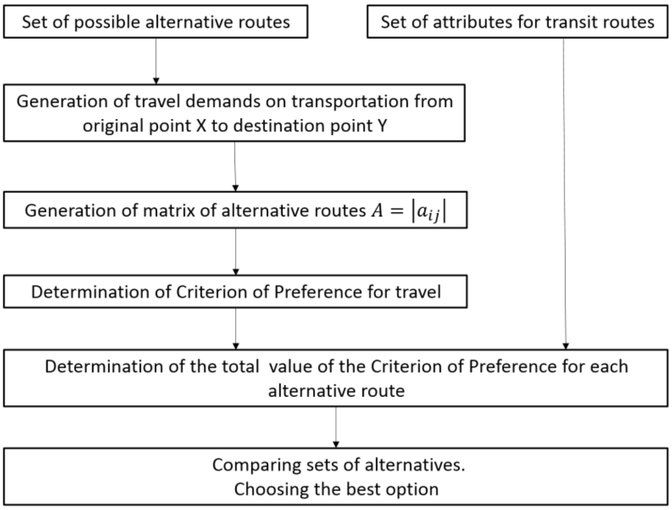


Fig.2. The decision making process in the large-scale transportation transit system

3. Definitions & Notations

The complex system is depicted using a structure of elements and connections. The restrictions on basis of elements are not imposed. The dynamic model of system's operation should provide opportunity to account for initiating events distribution in system and dynamics of their evaluation in time.

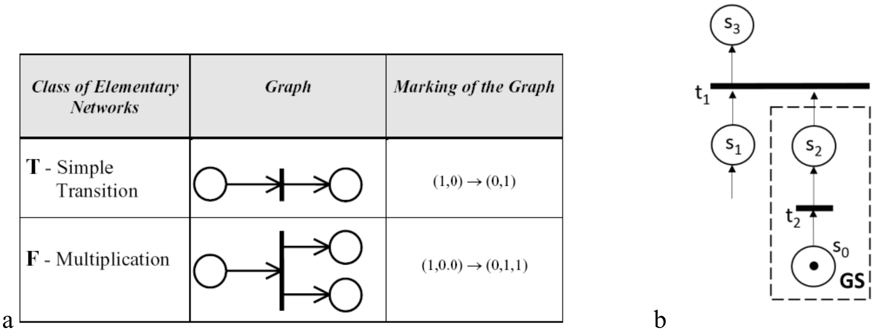
To make a decision based on the delivered problem we shall use the properties of Evaluation Petri Nets (E-Net)[18], formally defined as follows:

$$E = (P, T, I, Q, M) \tag{3}$$

where
$P = \{S\}$ – is a finite nonempty set of simple positions;
$T \neq \varnothing$ – is a finite nonempty set of transitions;
$I: T \rightarrow P$ – input and $Q: P \rightarrow T$ – output functions describing input and output arcs of each transition;
$M: P \rightarrow \{0,1\}$ – a marking of the graph (the tokens presence in the positions).

Any transition $t \in T$ can be described as $t = (\sigma, \tau, \pi)$, where
σ – is a type of an elementary network of transition;

τ – is a procedure of delay;
π – is a procedure of transformation.



Class of Elementary Networks	Graph	Marking of the Graph
T - Simple Transition		(1,0) → (0,1)
F - Multiplication		(1,0.0) → (0,1,1)

Fig. 3. (a) Class of elementary networks of Petri Net (b) Petri Net model for generator of schedules

We shall determine a class of elementary networks by a set $\sigma = \{T, F\}$, offered in[18], where T – simple transition, F – duplication (Fig. 3.a). In addition we upgrade this set by elementary network $= \{G, C\}$, where G is generator and C - absorber of tokens. For modelling of public transport with fix schedule we will use generator of schedules (GS), which shown at the Fig.3.(b). The transition t_1 is triggered when in the position s_1 is the mark (requirement for transportation has come) and in position s_2 is the mark from generator s_0 (public transport has appear in accordance with the schedule, when transition t_2 is triggered).

4. Model Construction

Process of E-net model design for choice alternative transport routes in the large-scale transportation transit system includes five main components:

1. The heuristic decision-making construction according to general scheme (Fig.2).
2. Graph of transportation transit system presented by directed finite graph which is an ordered pair $D = (V, A)$, where $V = \{v_i\}, i = \overline{1, n}$ is set of finite vertices (airports, railway, bus and bike stations and other passenger terminals) and $A = \{a_j\}, j = \overline{1, m}$ is set of finite arcs (transport lines between different terminals).
3. Formal method for transformation of transportation transit system graph into the Petri Net model.
4. Base set of modelling elements for above-mentioned transformation procedure.
5. Software tools for simulation experiment.

We shall build the dynamic model of system operation based on the general scheme (Fig.2) with set of elements (Fig. 3.a) to formalize the transformation of the general decision-making procedure to the graph of transportation transit system (Fig. 4.a) and then to E-net (Fig. 4.b). We shall interpret positions of E-net as condition of process, and transitions – as events, determined the change of condition. For design of E-net model we shall use the next rules.

1. Based on a set of alternative multimodal transportation routes (Fig. 1) the graph of transportation transit system is designed (Fig. 4.a).
2. The graph of transportation transit system transforms into the E-net model with set of elementary E-networks $\sigma = \{T, F, G, C\}$ and generators of schedules GS.
3. The start of modelling iteration of choice alternative of routes in the large-scale transportation transit system is displayed by elementary network $\sigma = \{G, F\}$. The transition t_0 generates the initial event of decision-making modelling for routes alternatives of passenger transportation $R_j, j = \overline{1, n}$.

4. The initial marking of the model. In the initial state of the model the token are present in the first positions of primary event generator, in the generators of scheduling and are absent in all other positions.
5. The time delay of transitions t_{ij} corresponds to the travel time or travel cost in accordance of defined Criterion of Preference (CoP).
6. Generators of scheduling have time delay of transitions t_{gs} which adequate to the timetable of corresponding public transport.
7. The process of the one modelling iteration is completed after filling the markers in the final positions s_f of the E-net.

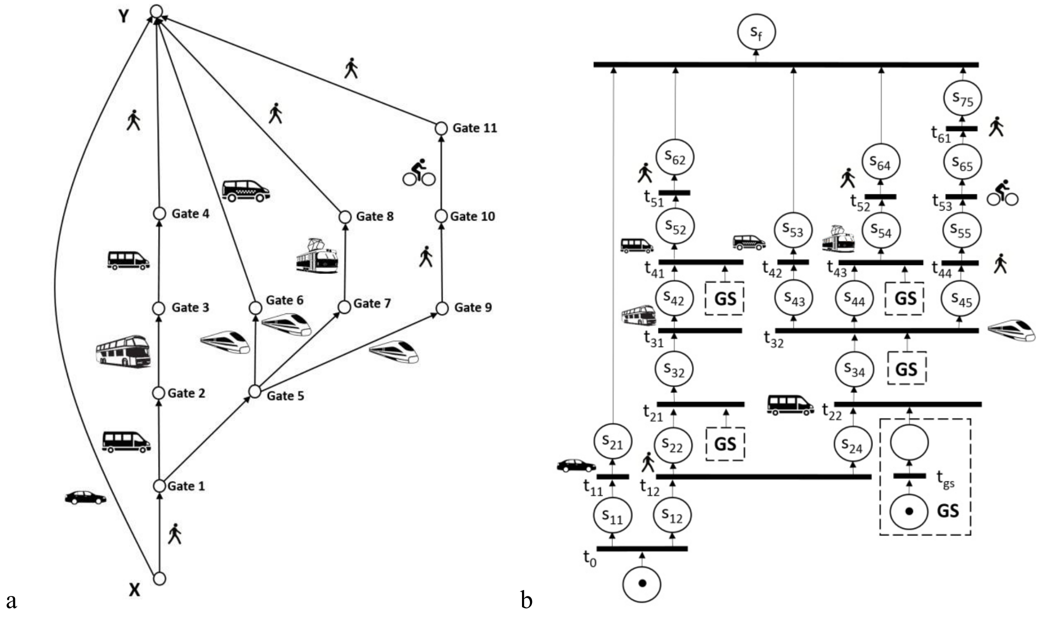


Fig. 4. (a) The graph of transportation transit system (b) Petri Net model of transportation transit system

This base set of modelling elements permits to formalize transformation of decision-making process to E-net and essentially to simplify construction of DSS dynamic empirical based models for choice alternative of routes in the large-scale transportation transit systems.

Further investigation of the obtained E-net can be carried out with the assistance of simulation tools and special software[19].

5. Conclusion

In the paper, a heuristics based decision support system for choosing alternative routes in the large-scale transportation transit system is described. Practical realization of DSS simulation on the base of Petri Net model is proposed.

Process of E-net model design for choice alternative of routes in the large-scale transportation transit system includes the next main components: the decision-making construction according to general heuristic scheme, formal method for transformation of decision-making construction into the graph of transportation transit system, formal method for transformation of transportation transit system graph into the Petri Net model, base set of modelling elements for above-mentioned transformation procedure and software tools. The detailed rules for design of Petri Net model make it easy to transform the initial heuristic selection criteria in formalized procedures of model construction. The proposed approach can be extended to the choice of alternative routes for the transportation of goods.

Acknowledgements

This work was supported by Latvian state research programme project “The Next Generation of Information and Communication Technologies (Next IT)” (2014-2017).

References

1. Zhang Xi, Jian Liu. Study on intelligent decision support system of railway empty wagon distribution in China. *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol. 5, pp. 272 - 284, 2005
2. Katsman M., Ph.D., Kryvopishyn O.,Lapin V. Mathematical models of decision support system for the head of the firefighting department on railways. *RT&A* # 03 (22), (Vol.2) 2011, September, pp. 86-93.
3. Rui Zhao, Dan Liu, Qibin Li. Decision support system design for rail transport of hazardous Materials. *Proceedings of the ICE Transport*, Volume 167, Issue 4, April 2013 pages 217 –231.
4. Kenneth L. Stott, Jr. and Burnie W. Douglas. A modelbased decision support system for planning and scheduling ocean borne transportation. *Interfaces*, Vol. 11, No. 4 (Aug., 1981), pp. 1-10.
5. Irina Yatskiv (Jackiva), Elena Yurshevich. Data actualization using regression models in decision support system for urban transport planning. Theory and engineering of complex systems and dependability. *Advances in Intelligent Systems and Computing*, Volume 365, 2015, pp. 553-561.
6. Jesus Gonzalez-Feliu, Josep-Maria Salanova Grau. VRP algorithms for decision support systems to evaluate collaborative urban freight transport systems. Lauras, M.; Zelm, M.; Archim`ede, B.; B´enaben, F.; Doumeignts, G. Enterprise *Interoperability*: I-ESA’14, ISTEWILEY, pp.196-201, 2015.
7. S. Ossowski, J. Hernandez, M. Belmonte, A. Fernandez, A. Garcıa-Serrano, J. Pe´rez-de-la-Cruz, J. Serrano and F. Triguero. Decision support for traffic management based on organizational and communicative multiagent abstractions. *Transportation Research,* Part C, Vol. 13, 2005, pp. 272-298.
8. Zhihong Jin, Qi Xu. The realization of decision support system for cross-border transportation based on the multidimensional database. *Journal of software*, Vol. 7, N 5, May 2012, pp. 974-981.
9. Eren Özceyla. A decision support system to compare the transportation modes in logistic. *International Journal of Lean Thinking*, Vol. 1, Issue 1 (June 2010), pp. 58-83.
10. Cathy Macharis,E. Pekin,A. Caris. A decision support system for intermodal transport policy. Brussels: VUB Press, 2008, 151 p.
11. Igor Kabashkin, Jelena Lučina. Development of the model of decision support for alternative choice in the transportation transit system. *Transport and Telecommunication*, 2015, volume 16, no. 1, 61–72.
12. B. Vannieuwenhuyse, L. Gelders, L. Pintelon, (2003). An online decision support system for transportation mode choice. *Logistics Information Management*, Vol. 16 Issue 2, pp.125 – 133.
13. Eugene Kopytov, Dmitry Abramov. Multiple-criteria analysis and choice of transportation alternatives in multimodal freight transport system. *Transport and Telecommunication*, 2012, Volume 13, No 2, 148–158.
14. Marek J. Druzdzel and Roger R. Flynn. Decision support systems. *Encyclopedia of Library and Information Science*, Second Edition, Allen Kent (ed.), New York: Marcel Dekker, Inc., 2002.
15. Rasmequan, S., Roe, C. and Russ, S.B. Strategic decision support systems: an experience-based approach. In: *18th IASTED Conference on Applied Informatics*, 14-17 February 2000, Innsbruck, Austria.
16. Samuel Holtzman. Intelligent decision systems. Addison-Wesley, Reading, MA, 1989.
17. Yi Zhao, Jian Lu, Hongtong Qiu. Applicability of Multi-modal Public Transport System Based on Accessibility Analysis. International Journal of Computer and Communication Engineering, Volume 4, Number 3, May 2015, pp. 211-218.
18. Nutt, G. Evaluation Nets for Computer Systems Performance Analysis. In: *Proceedings of the Fall Joint Computer Conference*. Montvale, New Jersey: AFIPS Press, Vol. 41, Part 1, December 1972, pp. 279-286.
19. The Logistics Performance Index and Its Indicators. World Bank. http://lpi.worldbank.org/

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